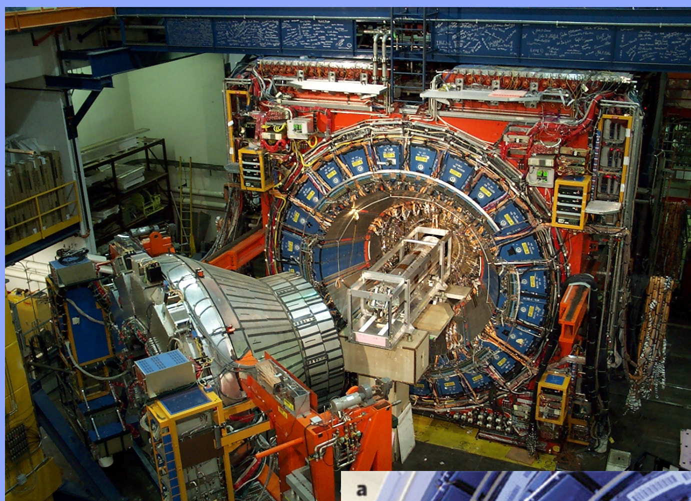
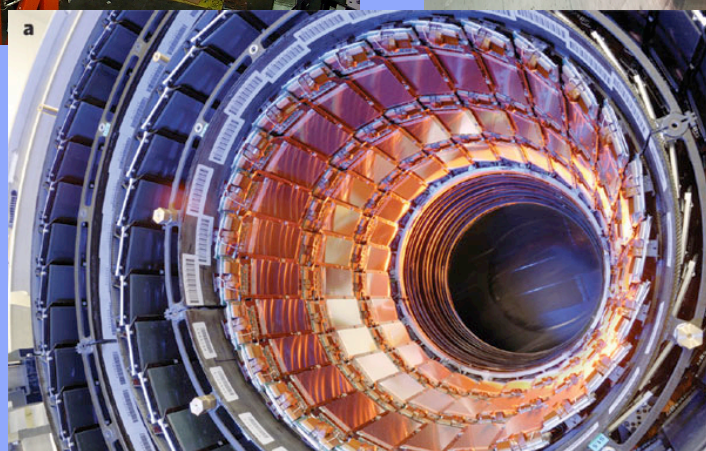
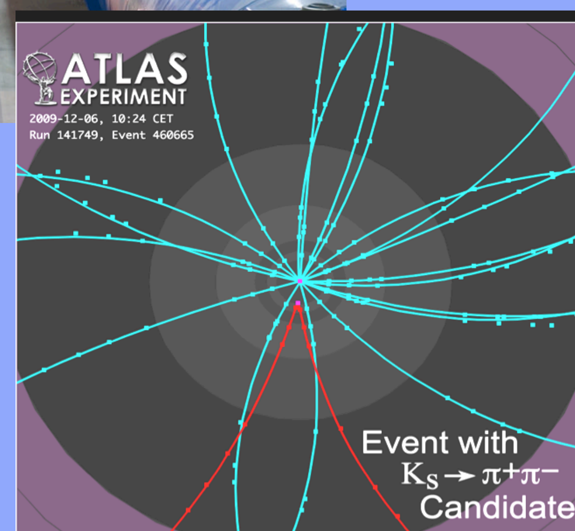
Particle Physics from Tevatron to LHC:
what we know and what we hope to discover







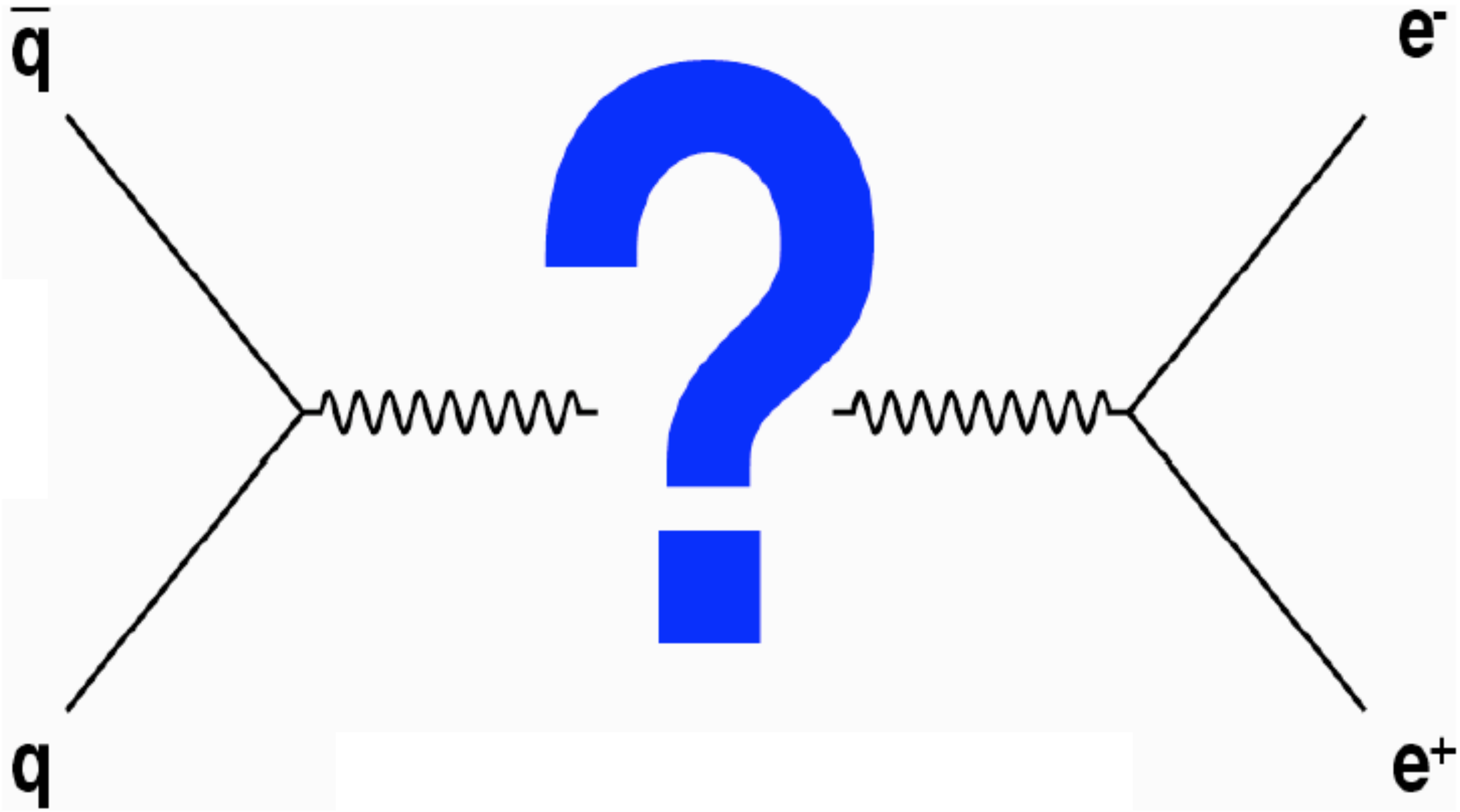
Beate Heinemann, UC Berkeley and LBNL

Università di Pisa, February 2010

Outline

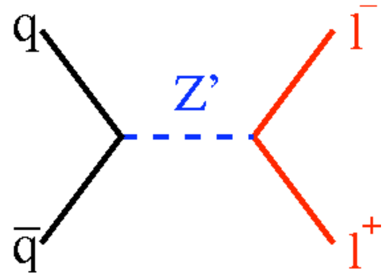
- **Introduction**
  - Outstanding problems in particle physics
    - and the role of hadron colliders
  - Current and near future colliders: Tevatron and LHC
- **Standard Model Measurements**
  - Hadron-hadron collisions
  - Cross Section Measurements of jets, W/Z bosons and top quarks
- **Constraints on and Searches for the Higgs Boson**
  - W boson and Top quark mass measurements
  - Standard Model Higgs Boson
- **Searches for New Physics**
  - Higgs Bosons (beyond the Standard Model)
  - Supersymmetry
  - High Mass Resonances (Extra Dimensions etc.)
- **First Results from the 2009 LHC run**

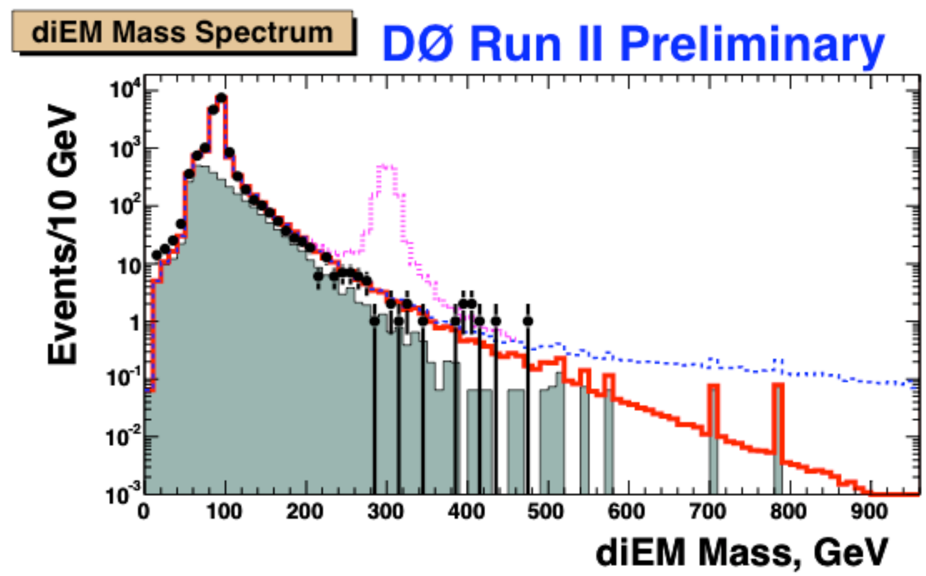
High Mass Resonances

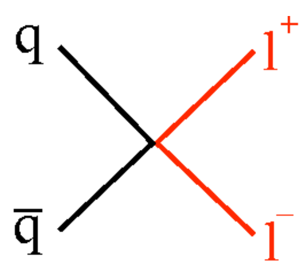


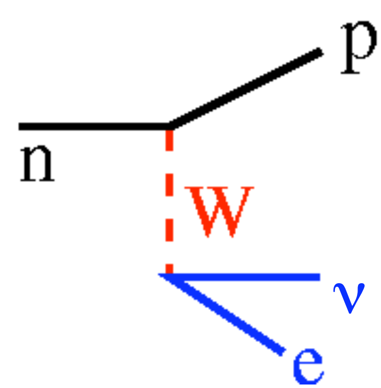
Resonances or Tails

- New resonant structure:
  - New gauge boson:
    - Z' $\rightarrow$ee, $\mu\mu$, $\tau\tau$, tt
    - W' $\rightarrow$eν, $\mu\nu$, $\tau\nu$, tb
  - *Randall-Sundrum* Graviton:
    - G$\rightarrow$ee, $\mu\mu$, $\tau\tau$, $\gamma\gamma$, WW, ZZ,…
- Tail:
  - Large extra dimensions *[Arkani-Hamed, Dvali, Dimopoulos (ADD)]*
    - Many many many resonances close to each other:
    - "Kaluza-Klein-Tower": ee, $\mu\mu$, $\tau\tau$, $\gamma\gamma$, WW, ZZ,…
  - Contact interaction
    - Effective 4-point vertex
      - E.g. via t-channel exchange of very heavy particle
    - Like Fermi's β-decay

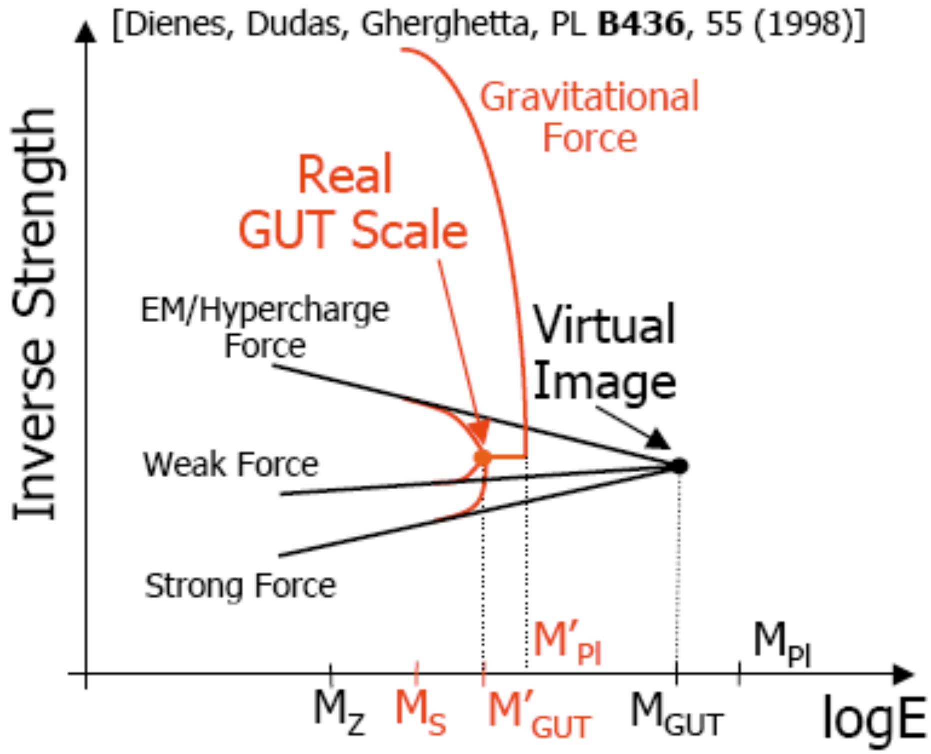








Large Extra Dimensions

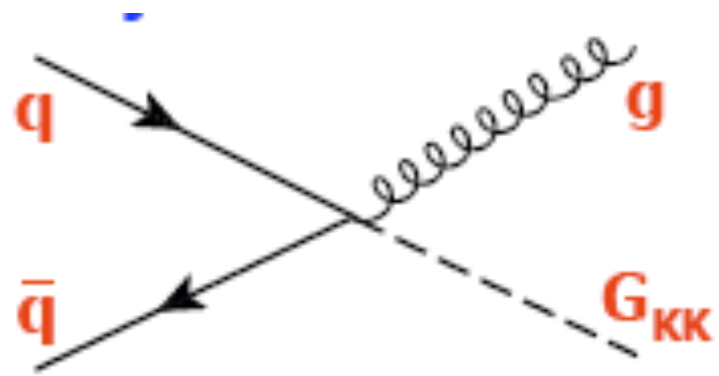


Arkani-Hamed, Dvali, Dimopoulos (1998)

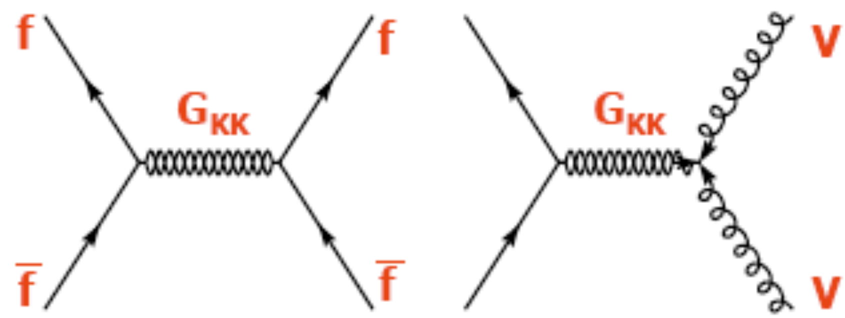
- Introduce extra spatial dimensions
  - Their presence weakens gravity
  - Gravity gets much stronger and only *appears* to be so weak
  - Addresses hierarchy problem

Collider Signatures of Extra Dimensions

- Monojets:
  - A graviton escapes



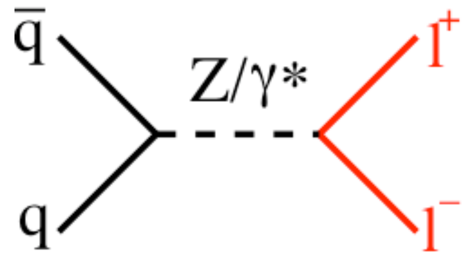
- Di-fermion or diboson resonances
  - Virtual exchange of graviton

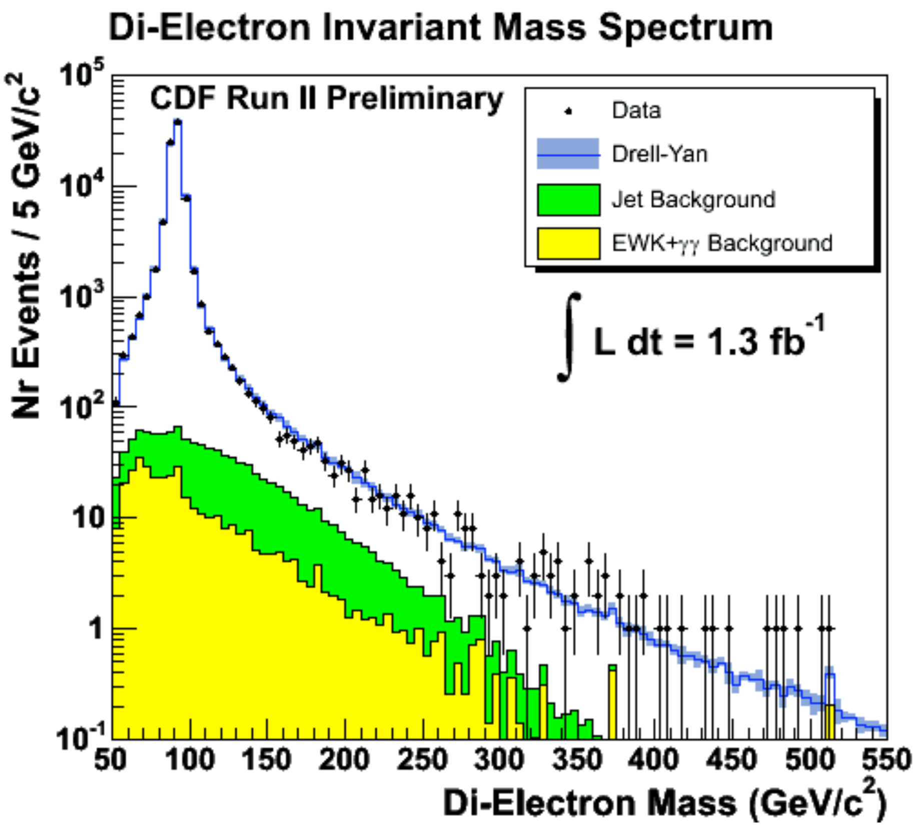


Alternative model by Randall, Sundrum (1999) predicts narrow resonances

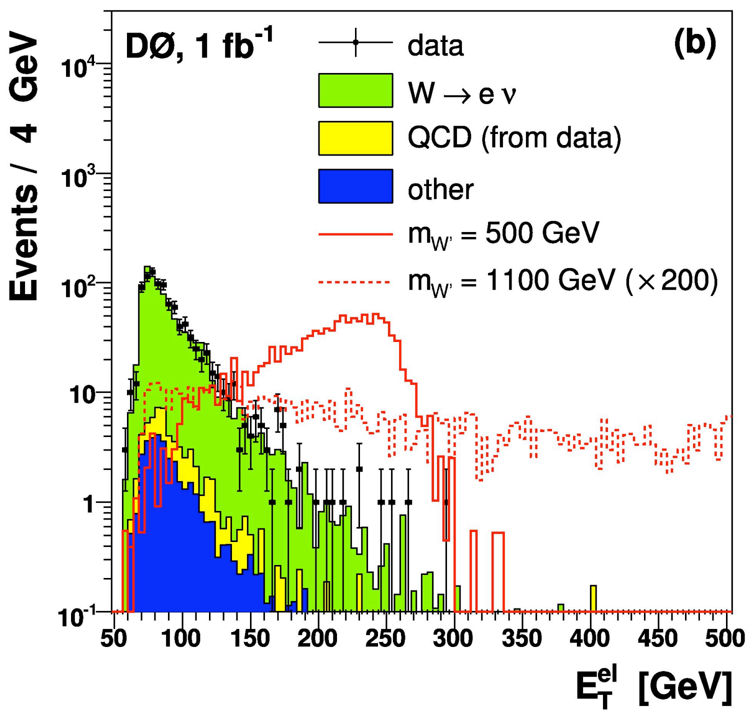
Dilepton Selection

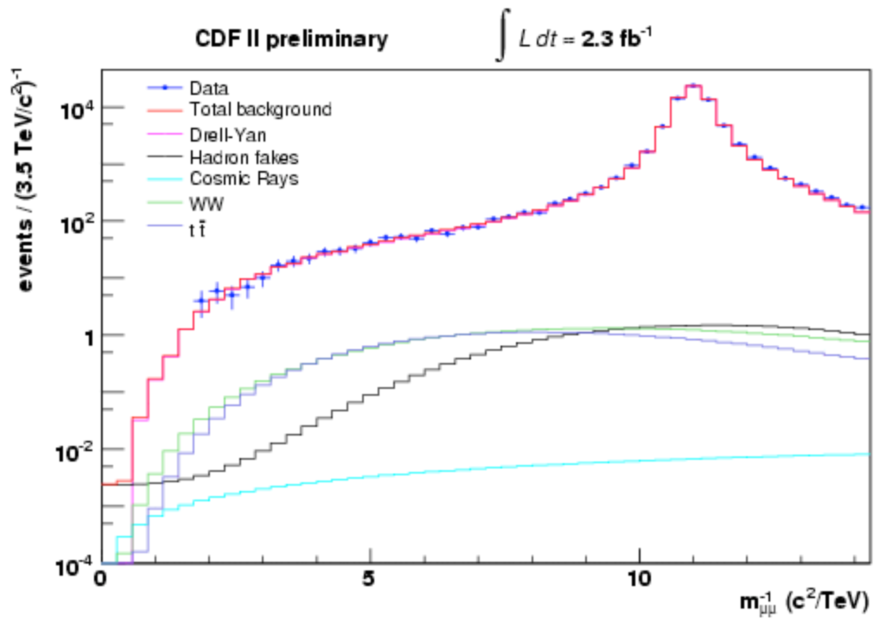
- Two high momentum leptons
  - irreducible background is Drell-Yan production
  - Other backgrounds:
    - Jets faking leptons: reject by making optimal lepton ID cuts
    - WW, diphoton, etc. very small
- Can search for
  - Dielectrons
  - Dimuons
  - Ditaus
  - Electron+muon
    - flavor changing
  - Dijets
  - ….

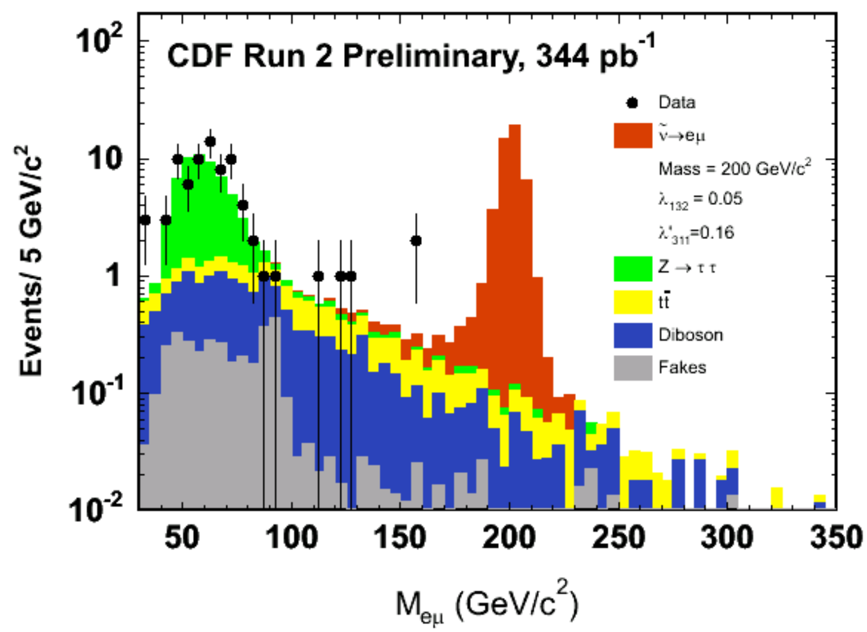




Spin-1 Bosons: Z' and W'

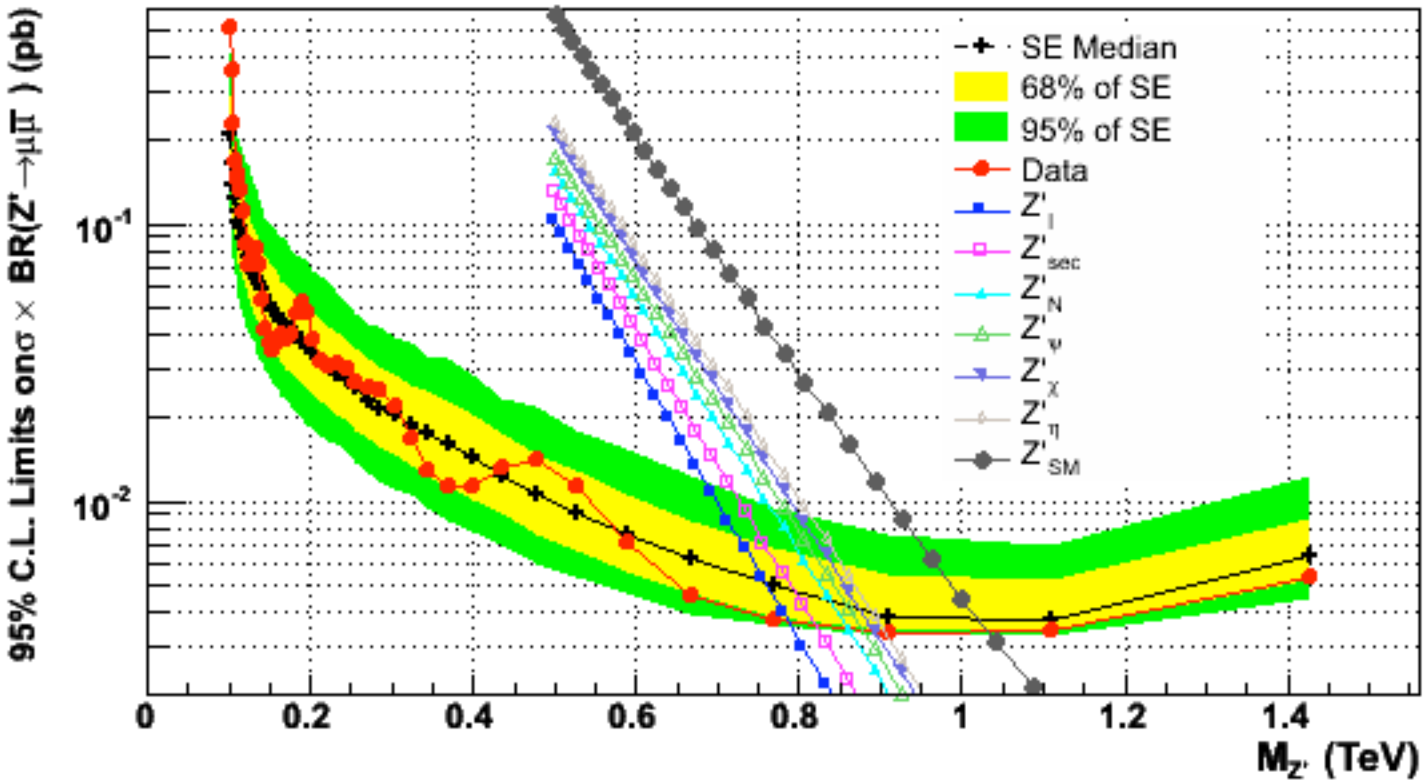






- 2 high P_T leptons:
  - ee, eν, μμ, eμ ….
- Data agree well with background

Interpreting the Mass plots

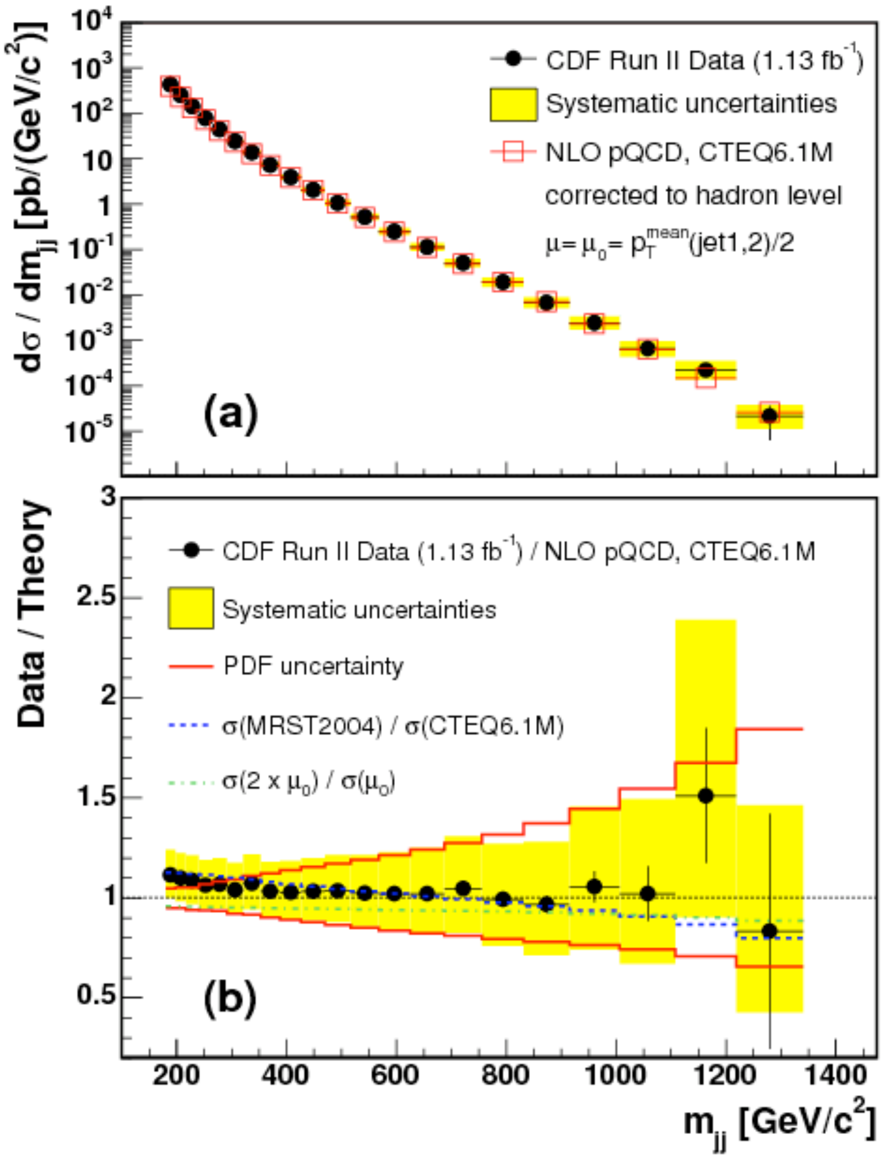


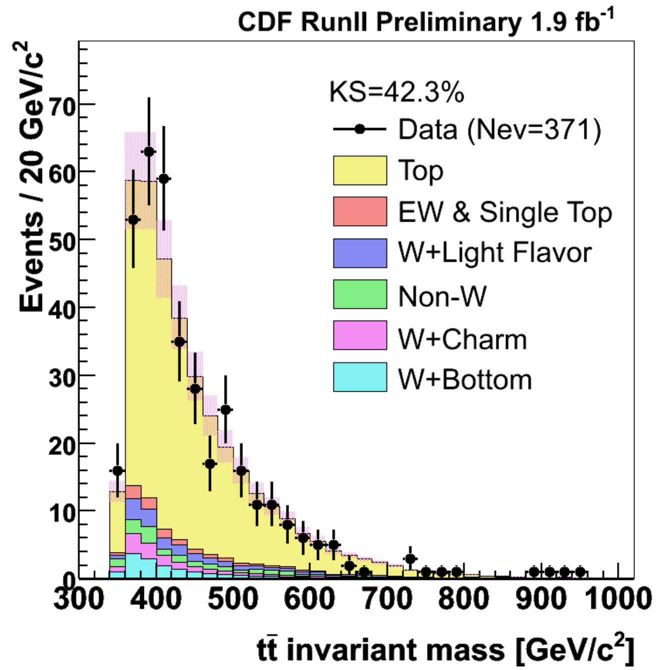
- Different curves represent different theoretical models
  - Mass limit depends on this
  - Cross section limit is independent of theory

For SM couplings:

	$Z' \to ee$	$Z' \to \mu\mu$
limit	>966 GeV	>1030 GeV

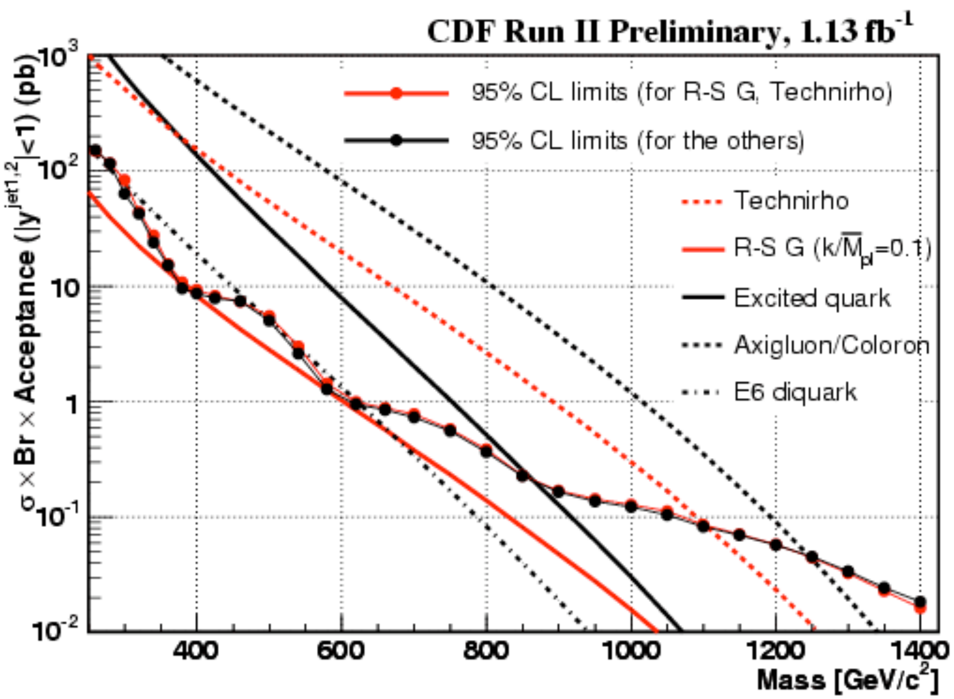
Resonances in Dijets and Ditop

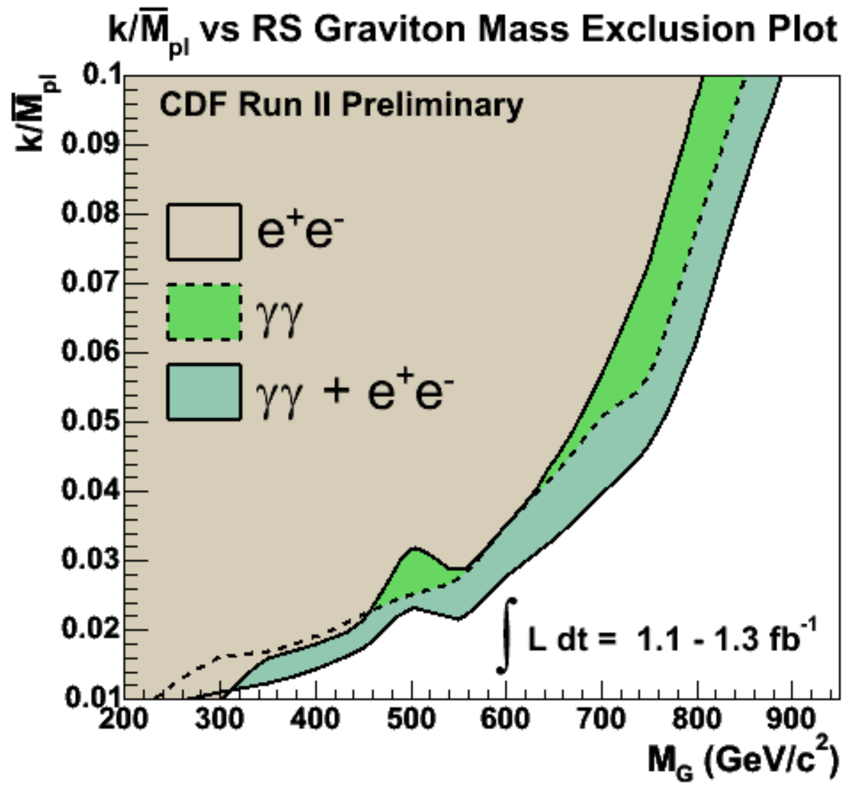




- Data agree well with background
- No sign of resonance structure

Constraints on Other Resonances

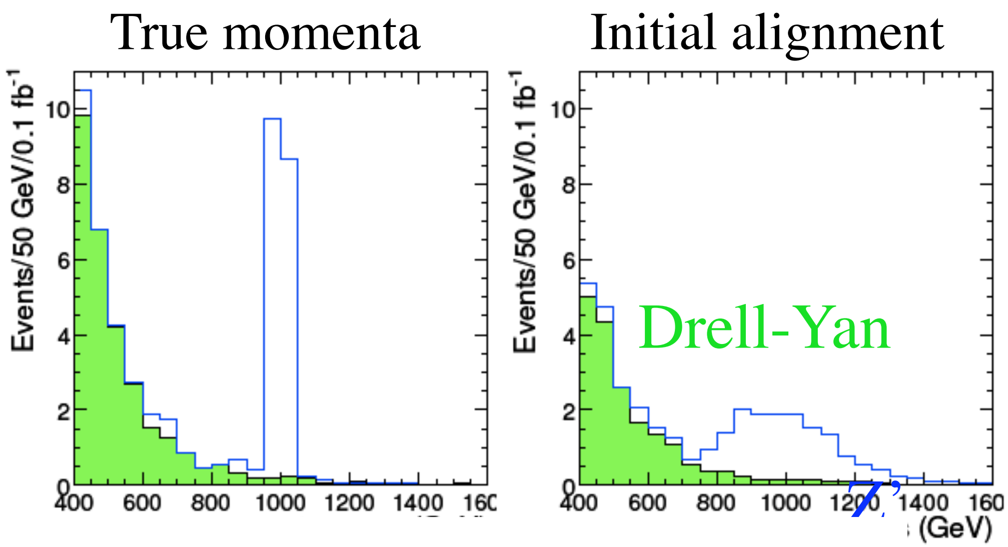




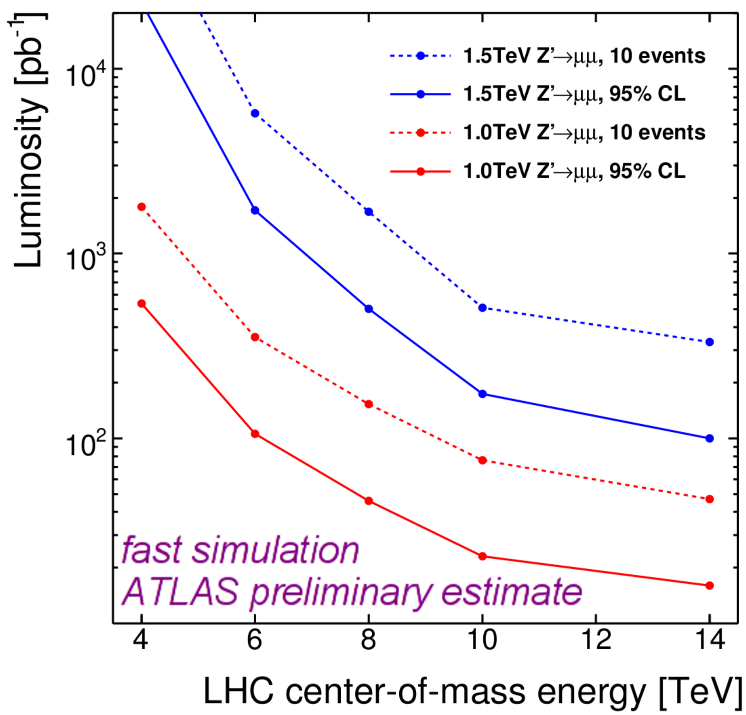
- Many models predict new resonances
  - Data constrain the masses and coupling strenghts

Z´ type particles should be easy at LHC!

- Signal creates clear peak
- Main background is well understood theoretically
- Applies to any narrow resonances decaying to
  - electrons, muons, photons
- Muons suffer from worsening resolution at high momentum



- **Sensitive to**
  - **1 TeV with L~100 pb^{-1}**
  - **1.5 TeV with L~1 fb^{-1}**



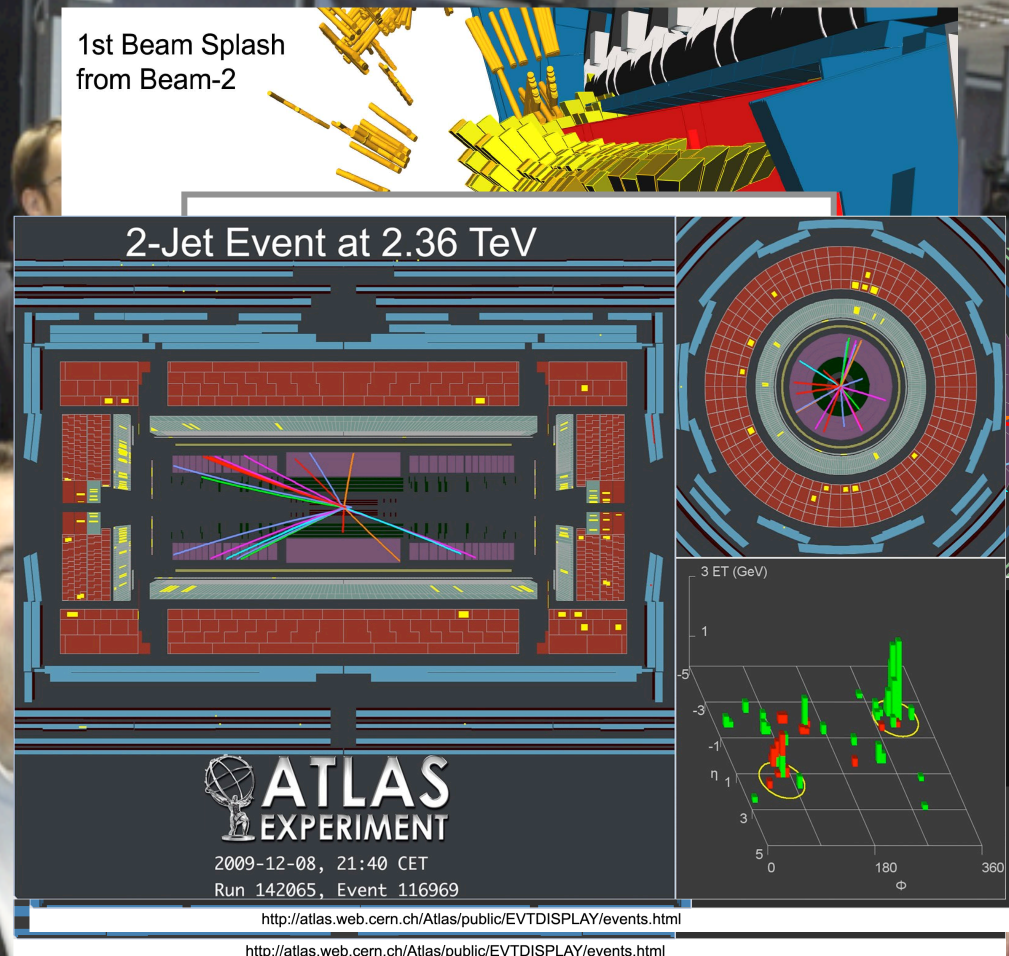
The 2009 LHC Run

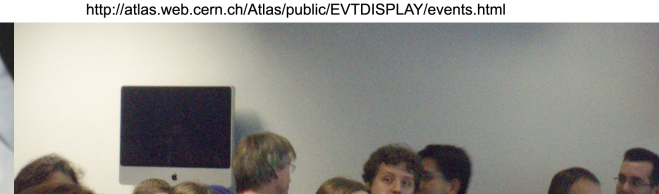

!!! BEAM AT ATLAS !!!
20-11-09 20:47

The 2009 Run

Lots of firsts!:

- <u>Nov. 20</u>: single beam splash
- <u>Nov. 23</u>: first 900 GeV collisions (solenoid off)
- <u>Dec. 6</u>: first collisions with “stable” beam. Full inner detector on for the first time
- <u>Dec. 8</u>: first collisions at 2.36 TeV: highest energy collisions ever!
- <u>Dec. 16</u>: end of 2009 data-taking (Oufff…)



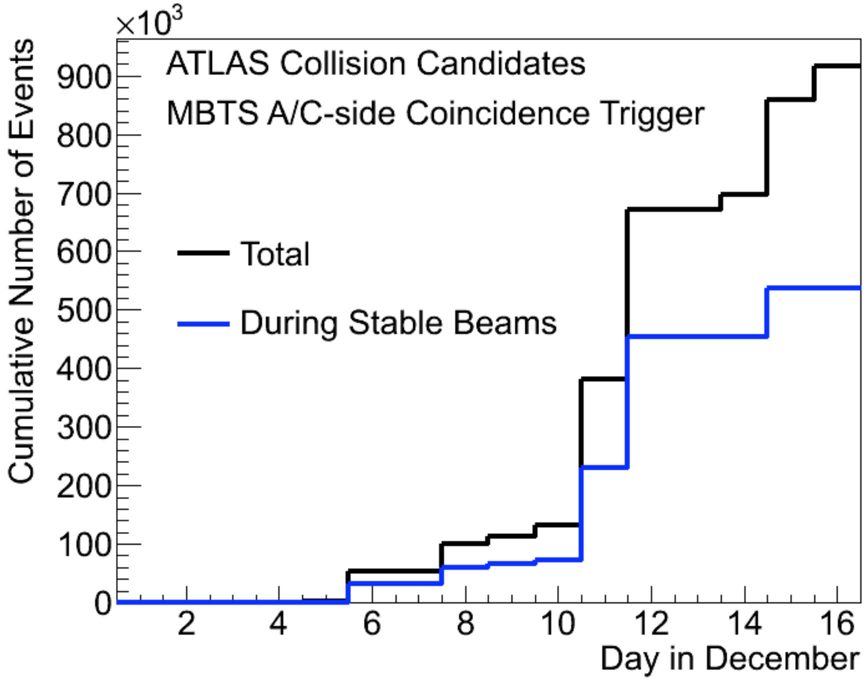


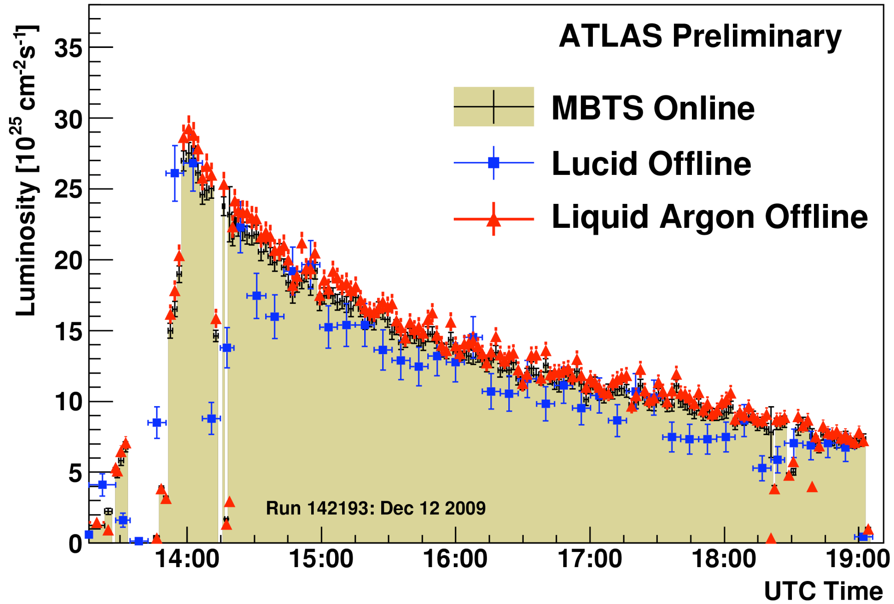
Detector is fully operational

Subdetector	Number of Channels	Operational Fraction
Pixels	80 M	97.9%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	98.2%
LAr EM Calorimeter	170 k	98.8%
Tile calorimeter	9800	99.2%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.4%
RPC Barrel Muon Trigger	370 k	98.5%
TGC Endcap Muon Trigger	320 k	99.4%
LVL1 Calo trigger	7160	99.8%

- Pixels and Silicon strips (SCT) at nominal voltage only with stable beams
- Solenoid and/or toroids off in some periods
- Muon forward chambers (CSC) running in separate partition for rate tests

Summary of Data Taking in ATLAS

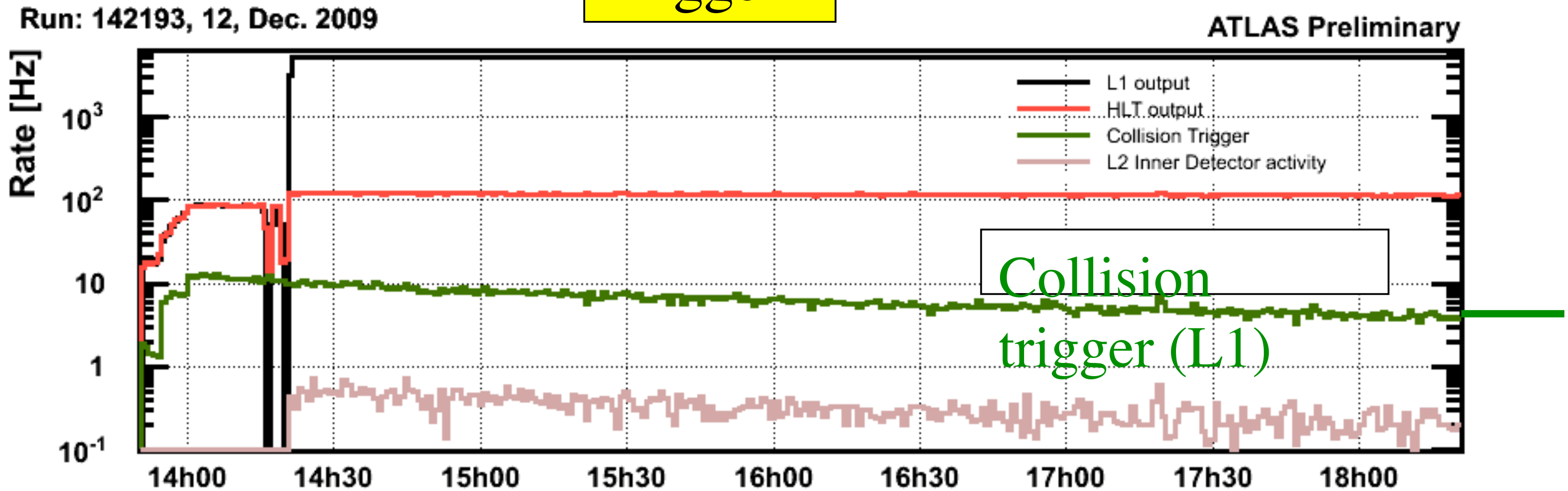


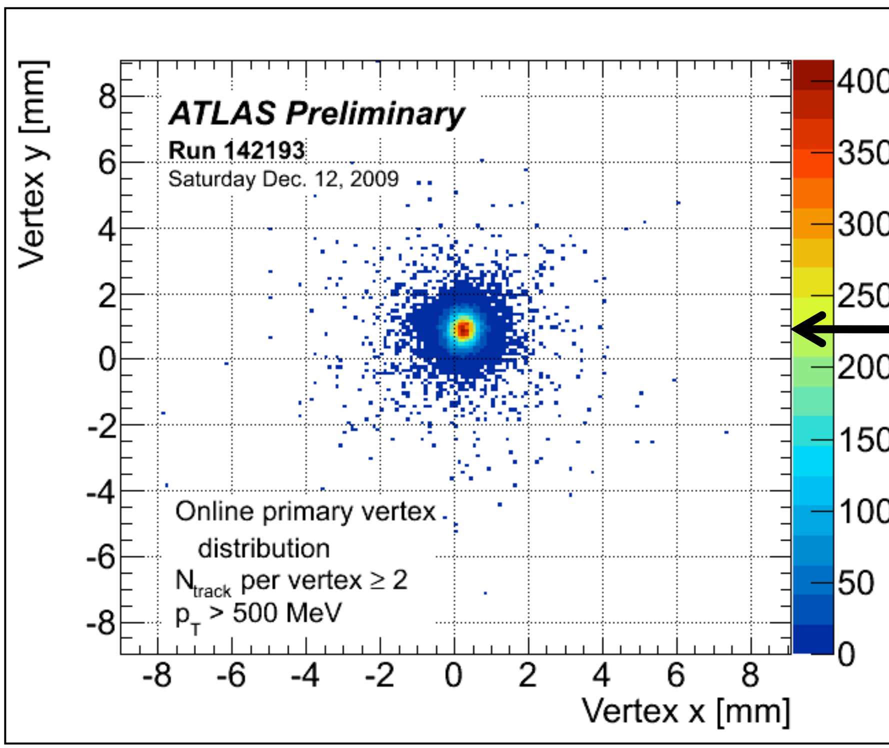


Recorded data samples	Number of events	Integrated luminosity (< 30% uncertainty)
Total	~ 920k	~ 20 μb^{-1}
With stable beams (→ tracker fully on)	~ 540k	~ 12 μb^{-1}
At $\sqrt{s}$=2.36 TeV (flat top)	~ 34k	≈ 1 μb^{-1}

Average data-taking efficiency: ~ 90%

Trigger



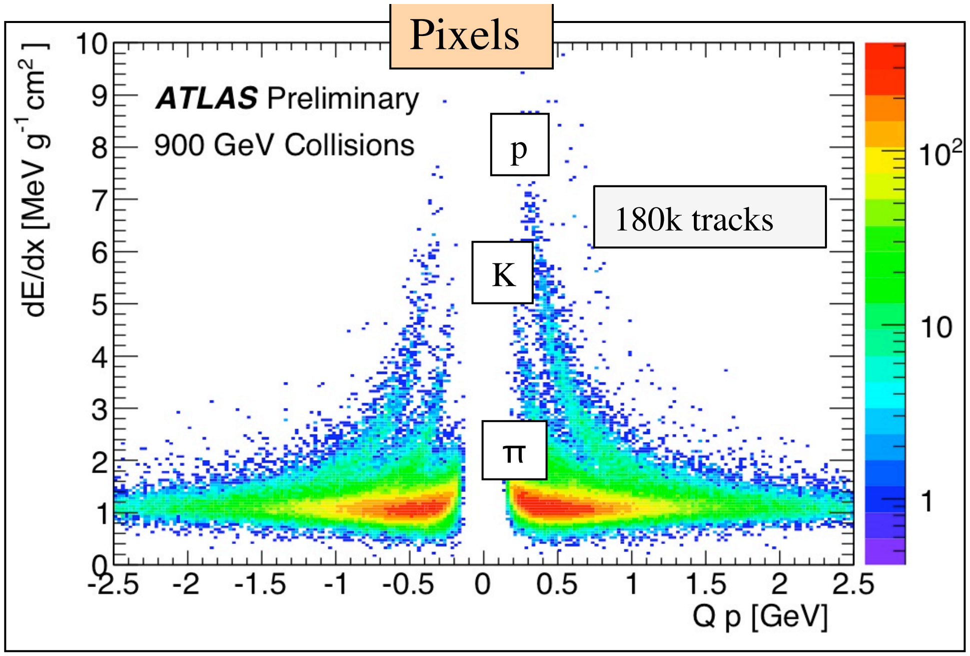


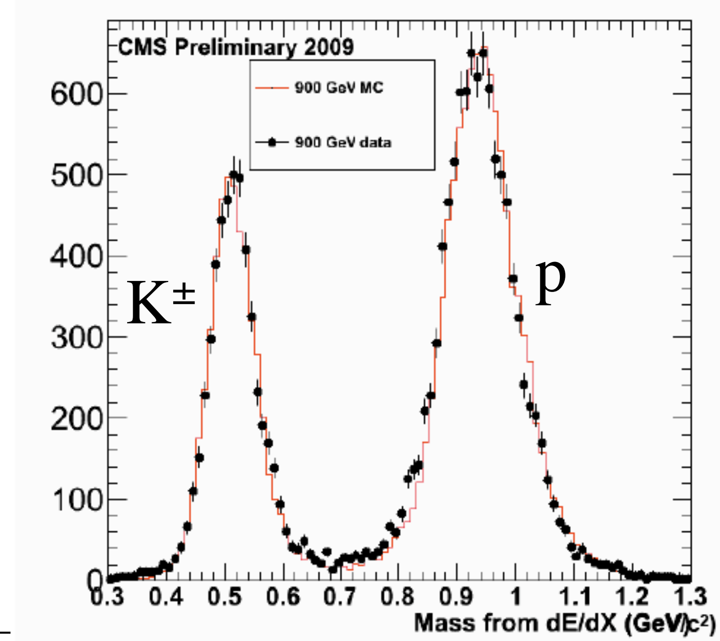
Online determination of the primary vertex and beam spot using L2 trigger algorithms

Spot size ~ 250 μm

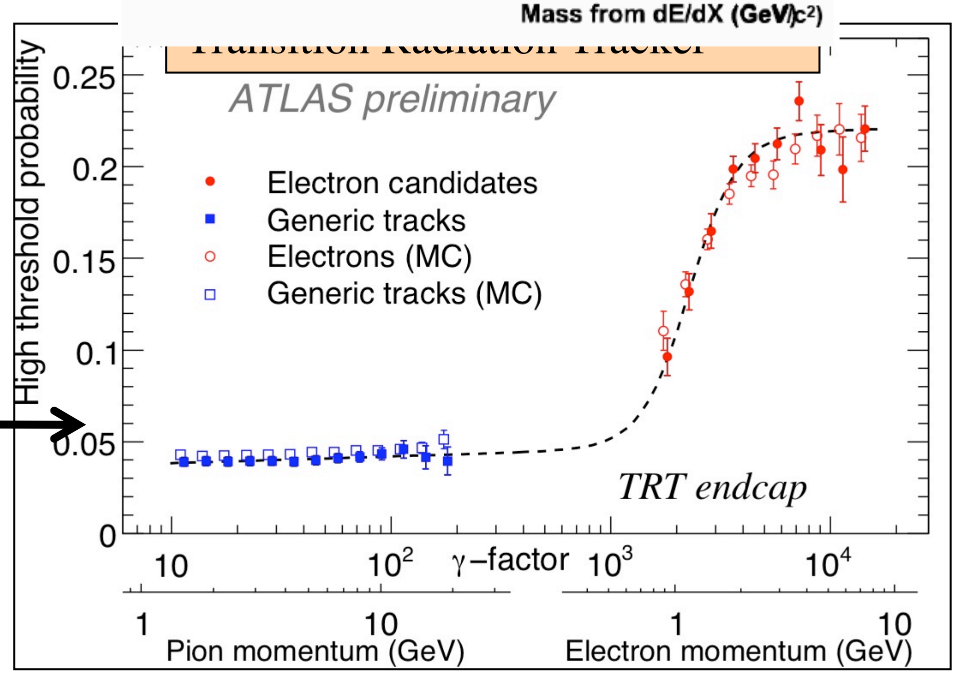
Particle Identification

$$M = p\sqrt{\left(\frac{dE}{dx} - C\right)K^{-1}}$$



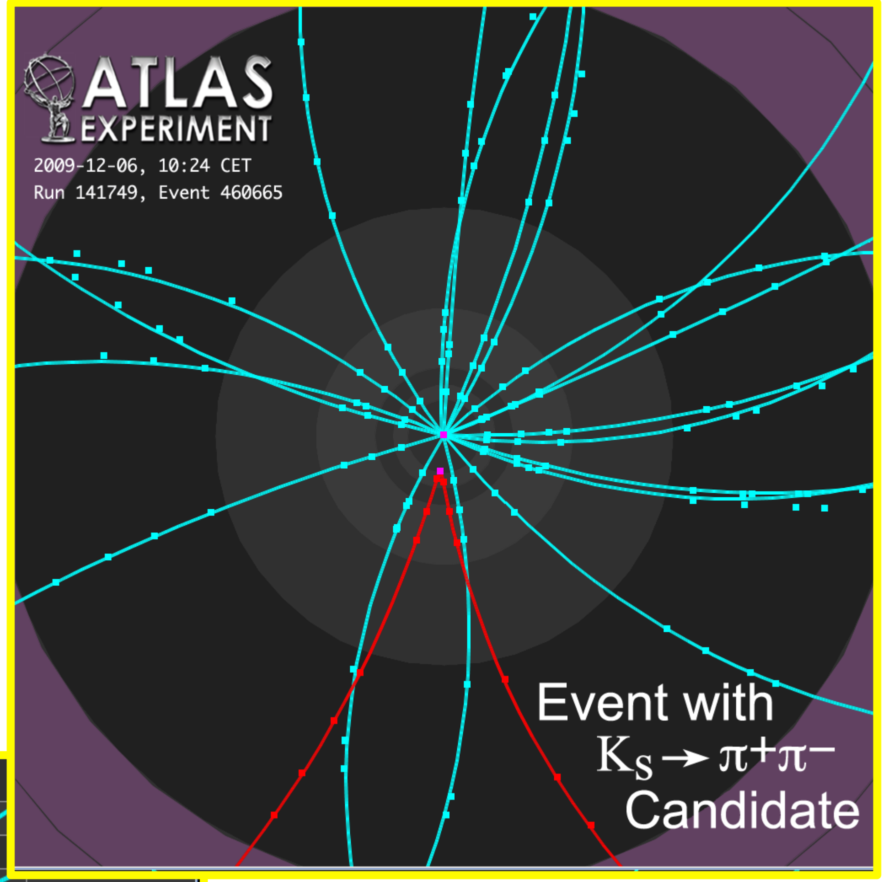


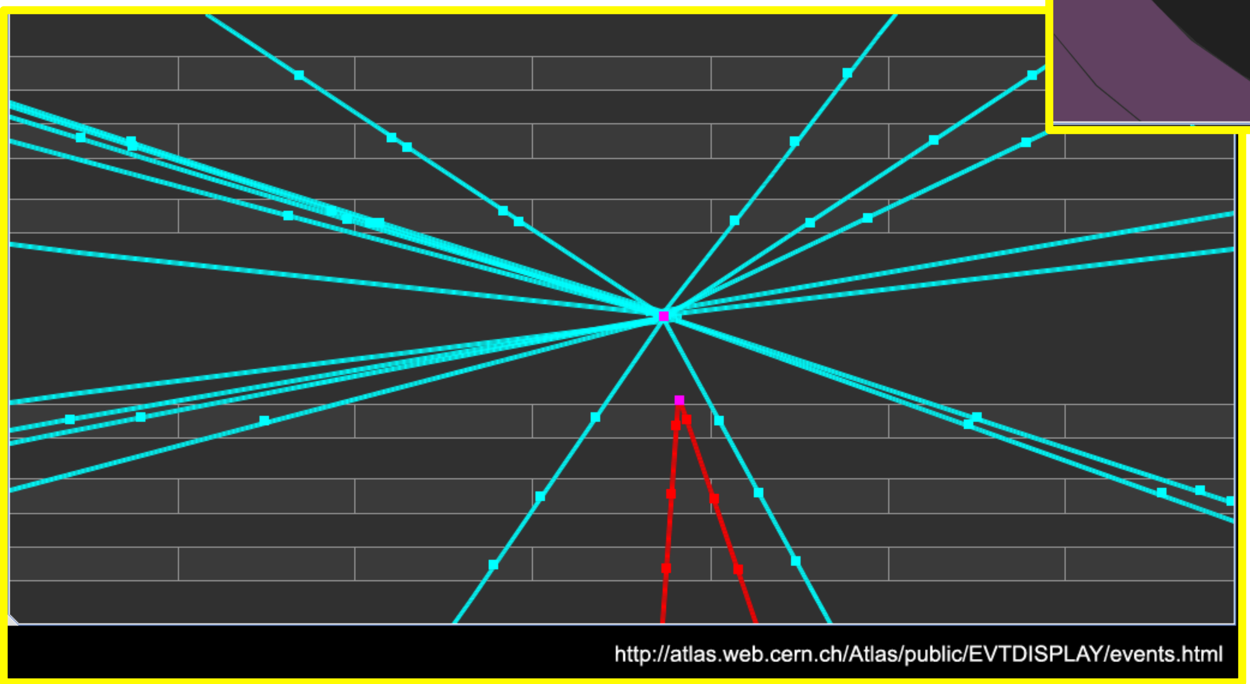
Transition radiation intensity is proportional to particle relativistic factor γ=E/mc^2.



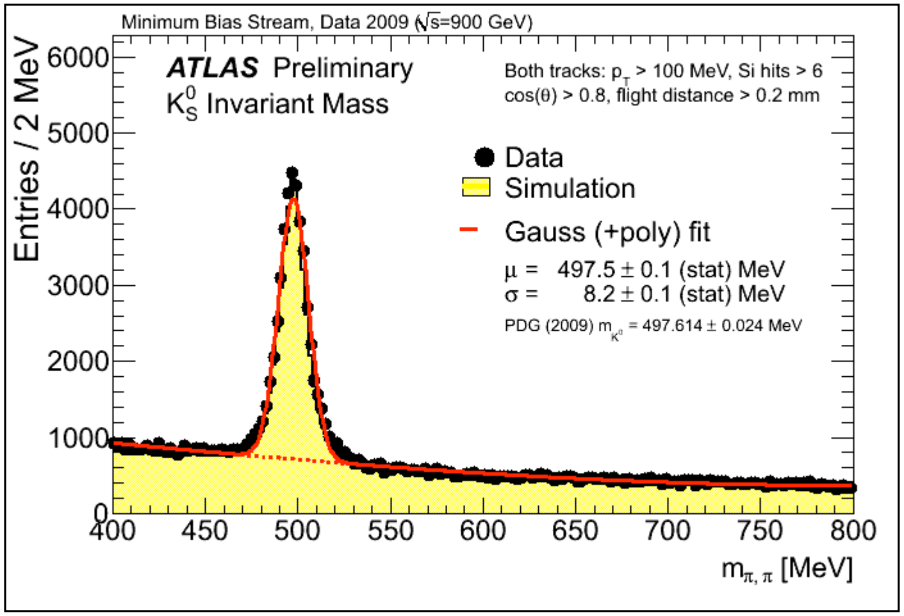
Sunday 6 December: machine protection system commissioned

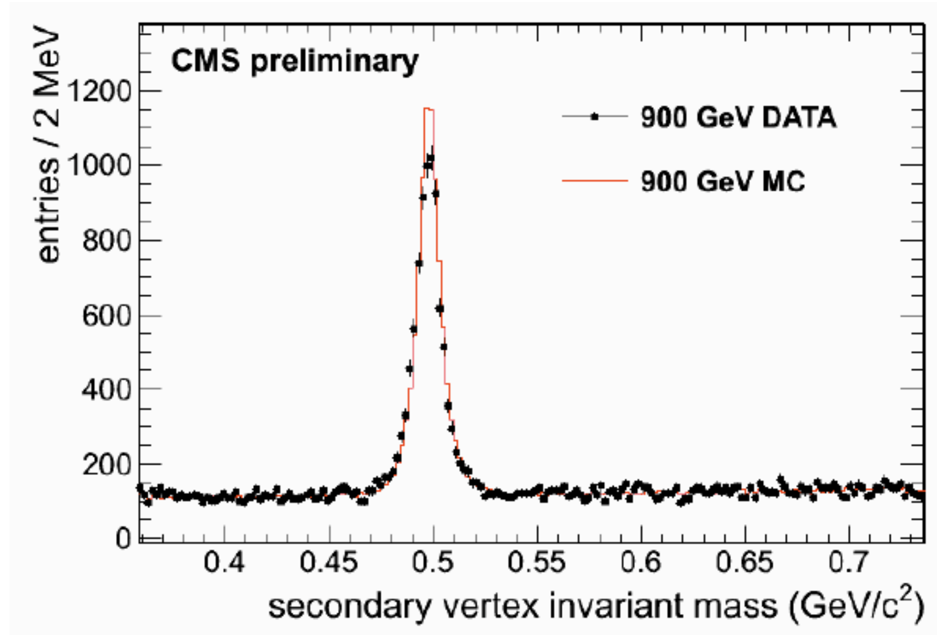
→ stable (safe) beams for first time
→ full tracker at nominal voltage
→ whole ATLAS operational

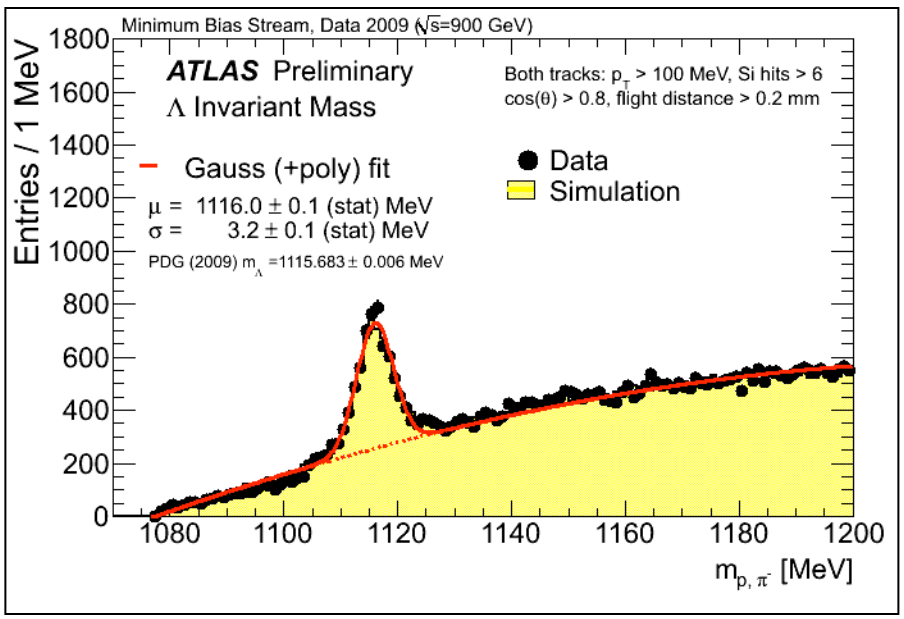




Observing well-known Resonances



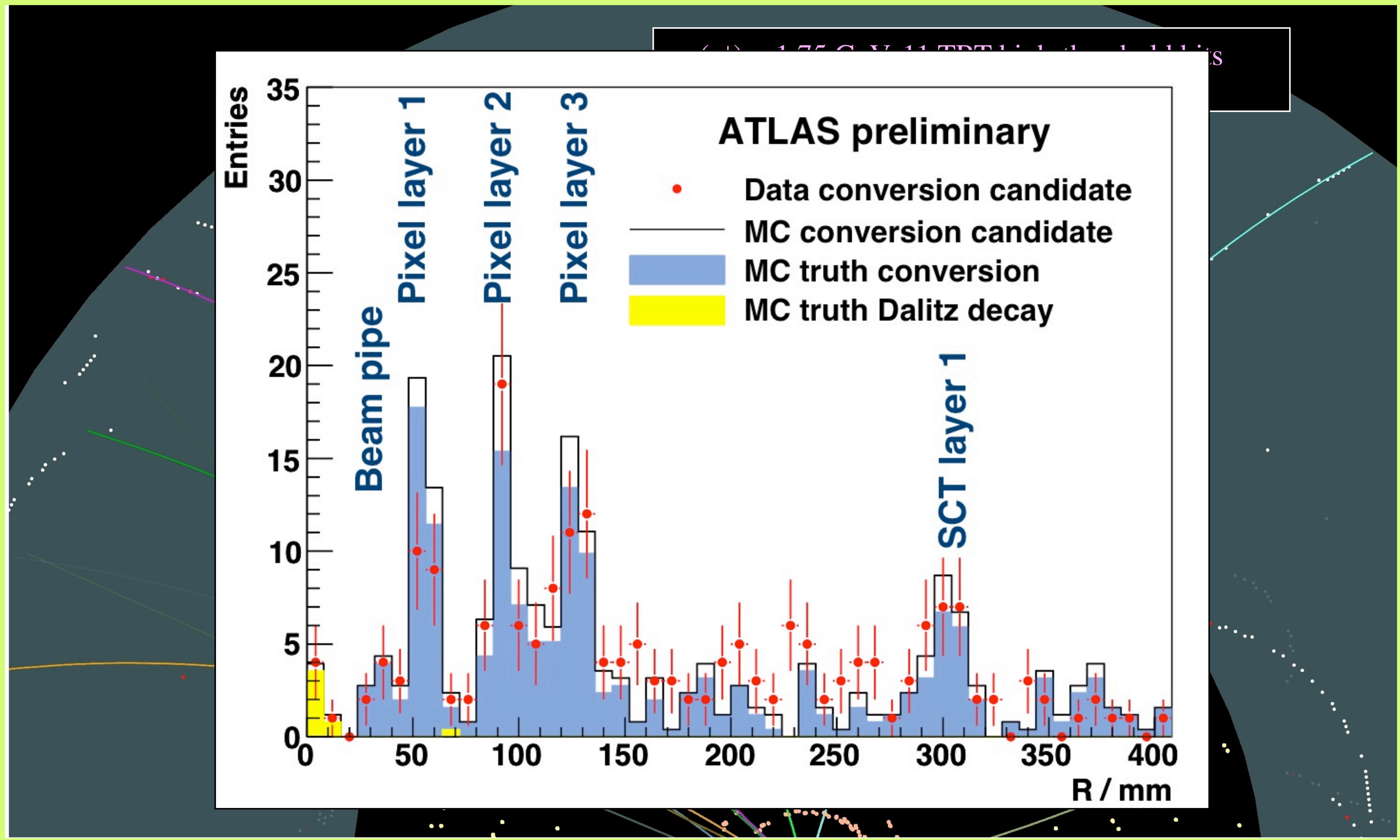




$$K^0_s \rightarrow \pi^+\pi^-,\ \Lambda \rightarrow p\pi^-$$

- Excellent agreement between data and simulation

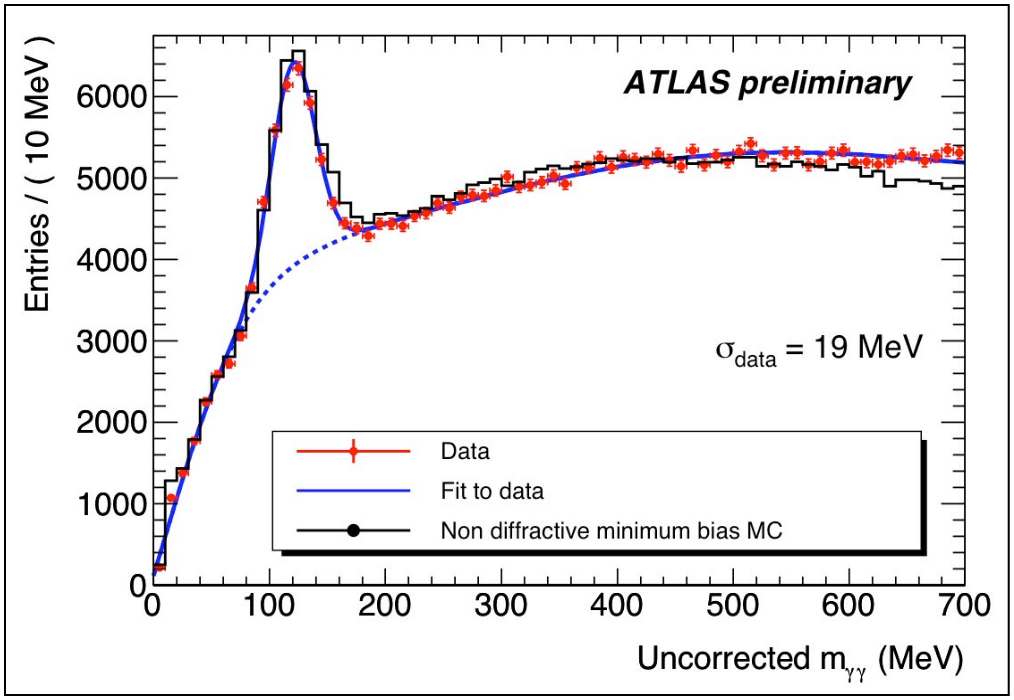
Photon Conversions: $\gamma \rightarrow e^+e^-$

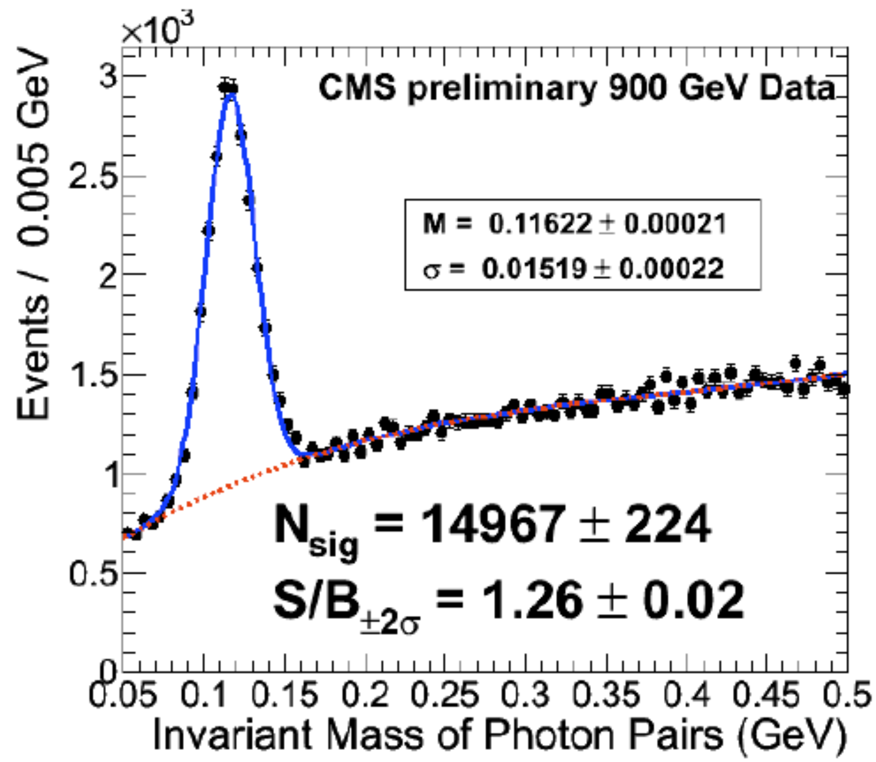


- Probe material inside the tracker volume

Resonances in the Calorimeter: $\pi^0 \rightarrow \gamma\ \gamma$

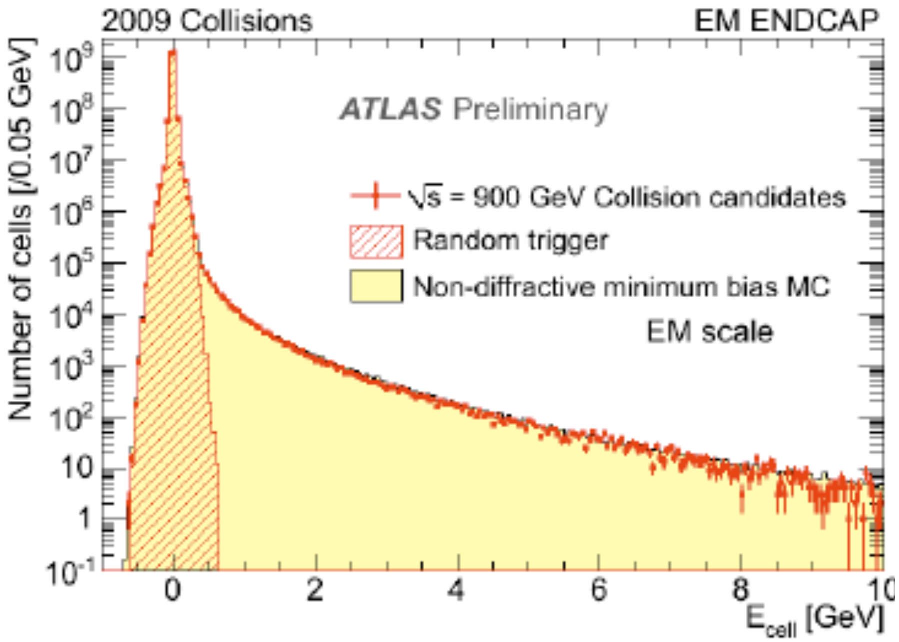
$\pi^0 \rightarrow \gamma\gamma$

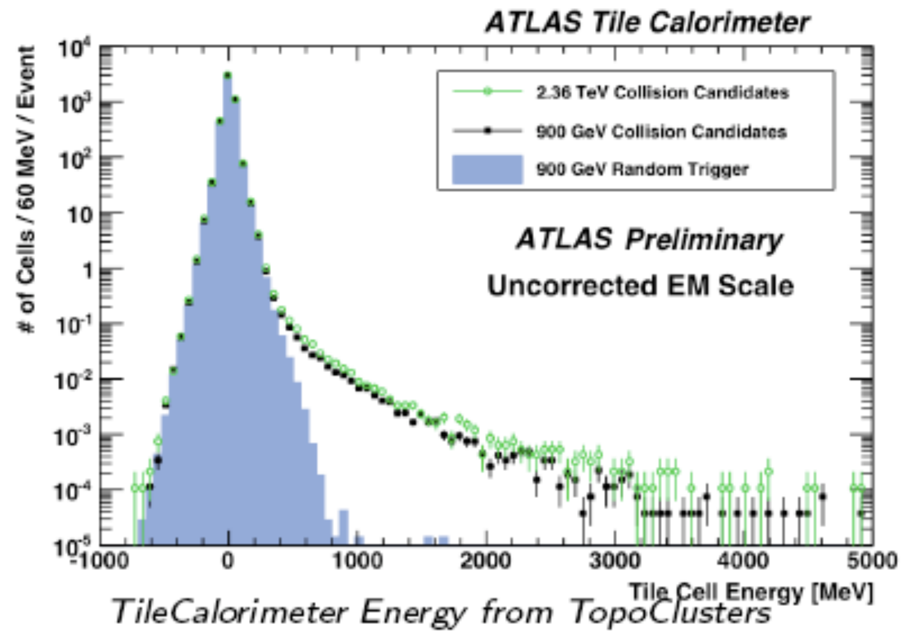




- Photon candidates: E>300 MeV
- No corrections for energy loss before calorimeter
- Data and simulation agree very well

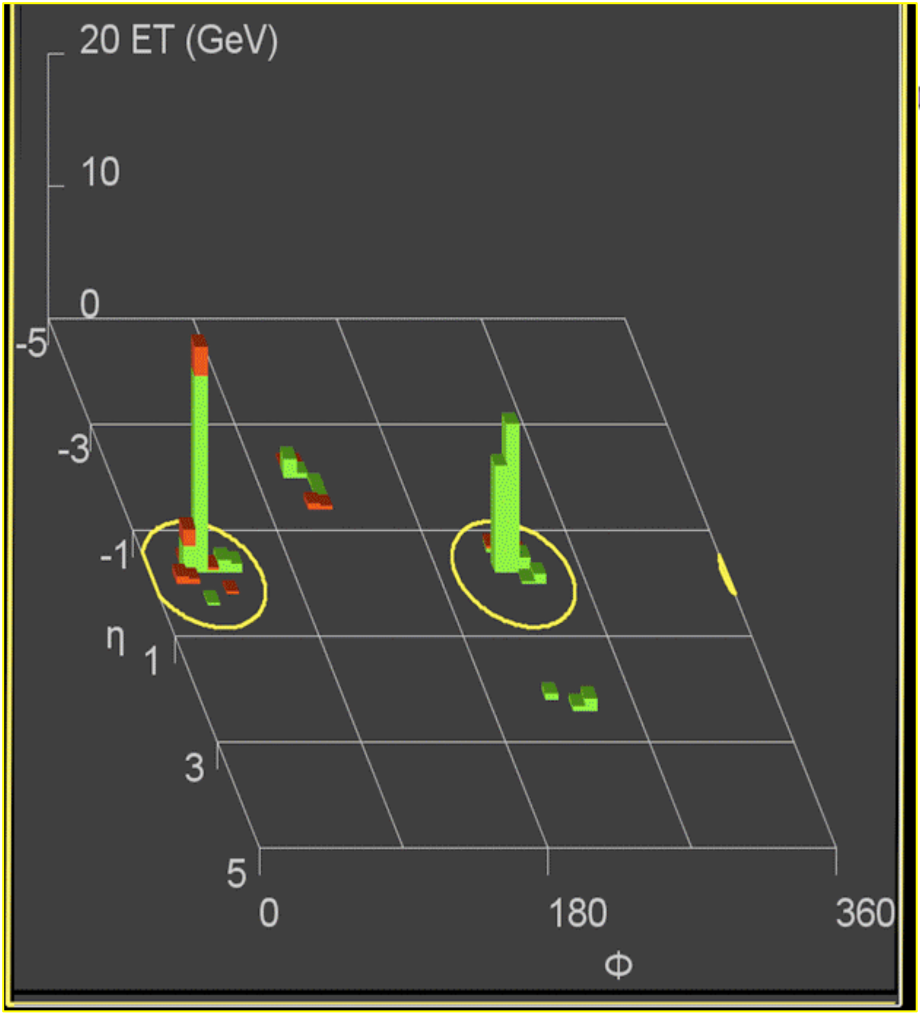
Calorimeter Energies

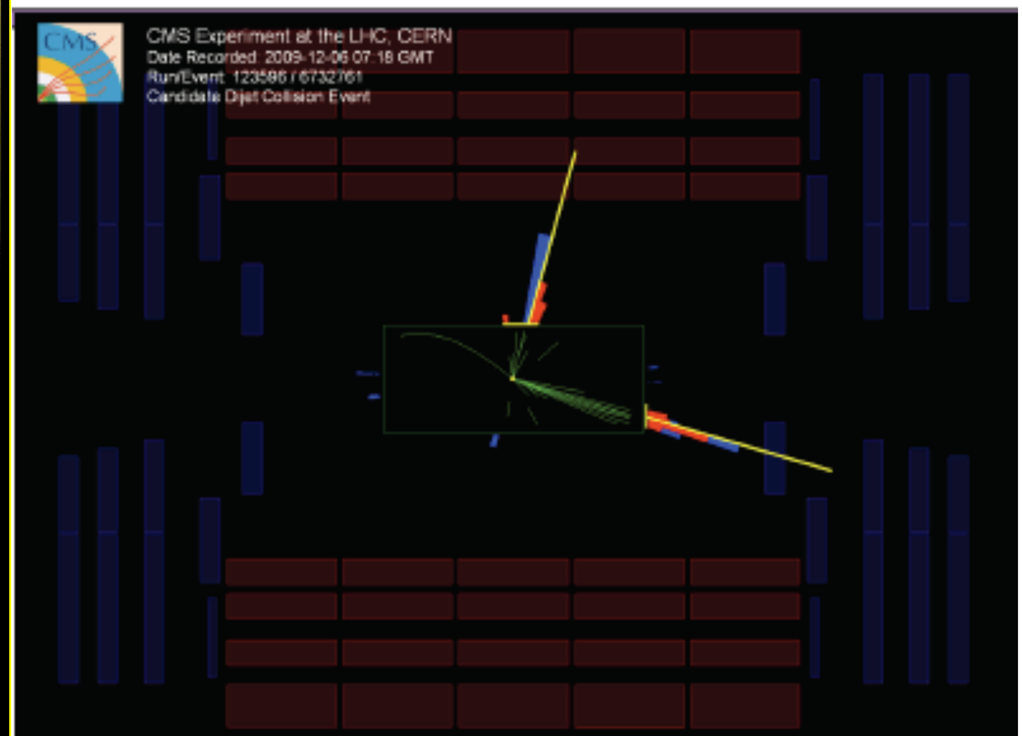




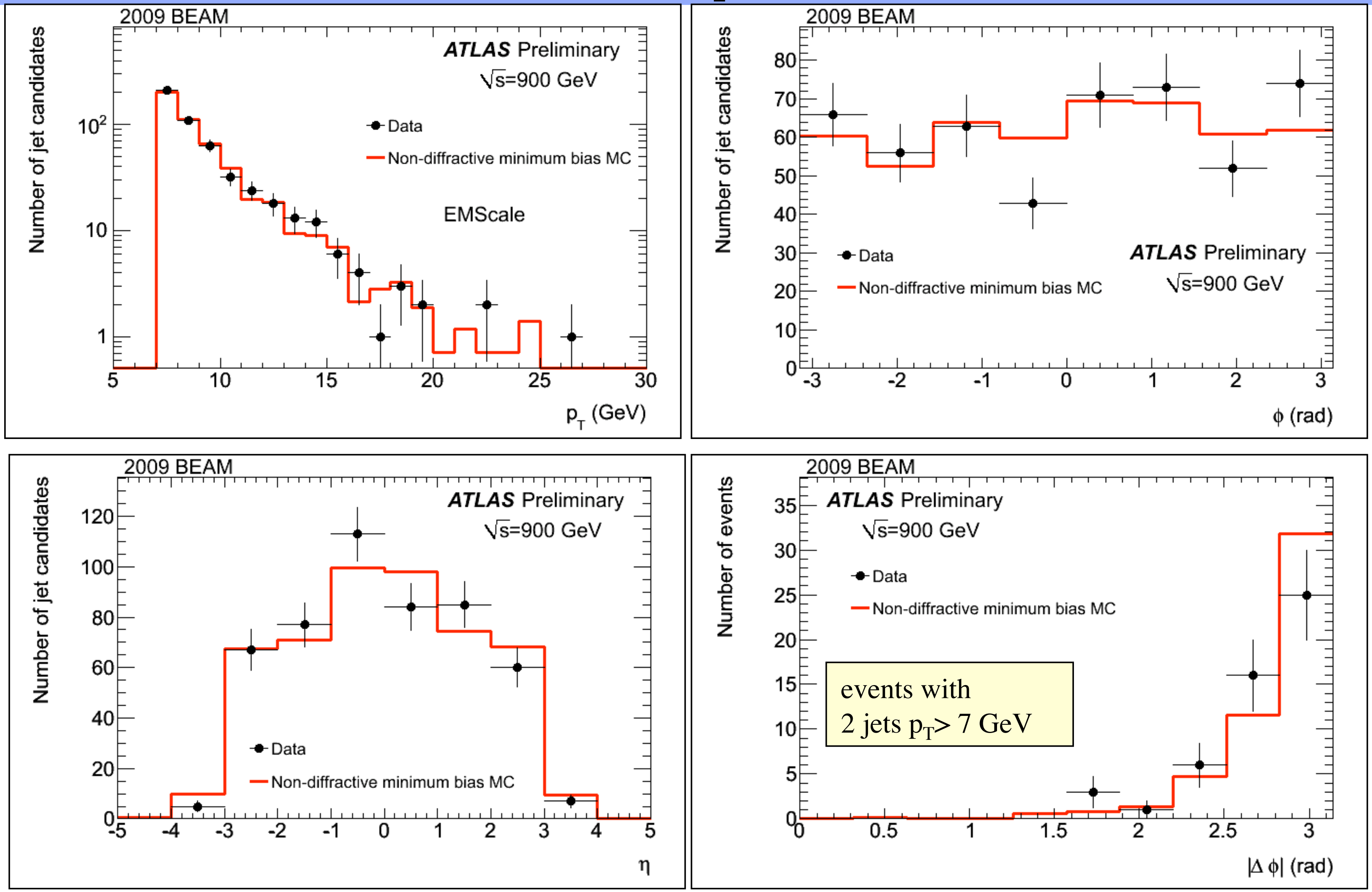
- Cell energy distribution in LAr calorimeter very well described by simulation
- Observe that higher energies are present at higher centre-of-mass energy in Tile calorimeter

First Jets in ATLAS and CMS





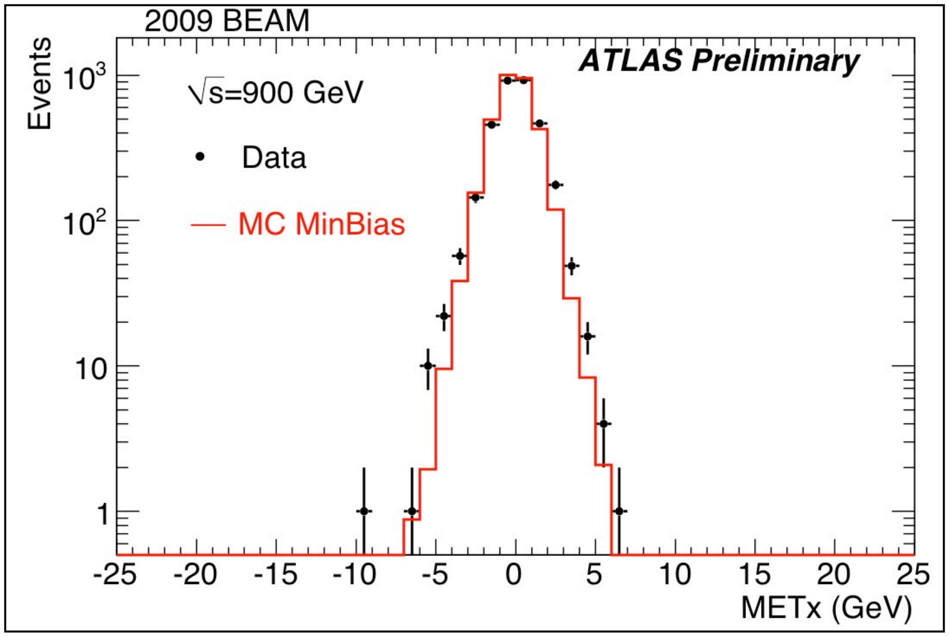
Kinematic Properties of Jets

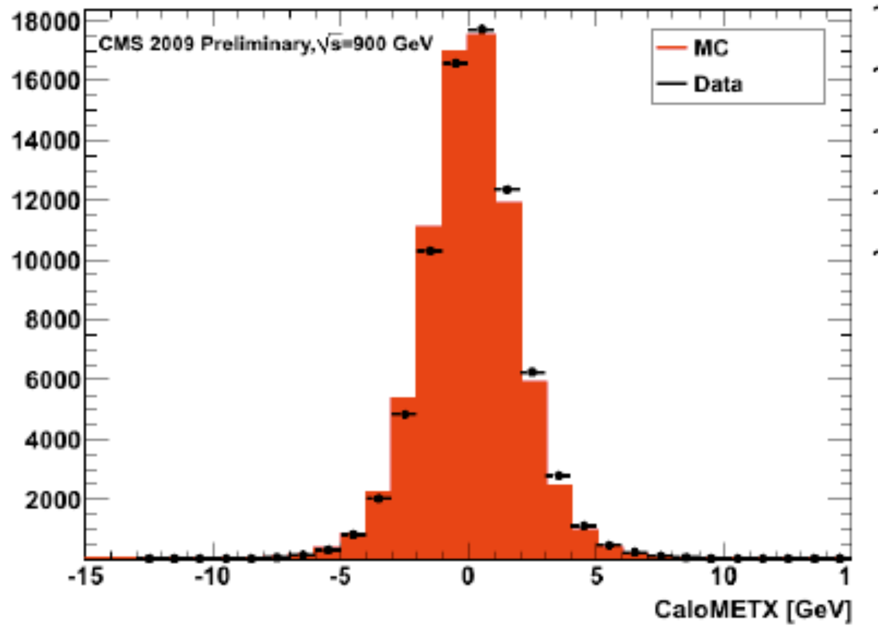


- Shape agrees well between data and simulation

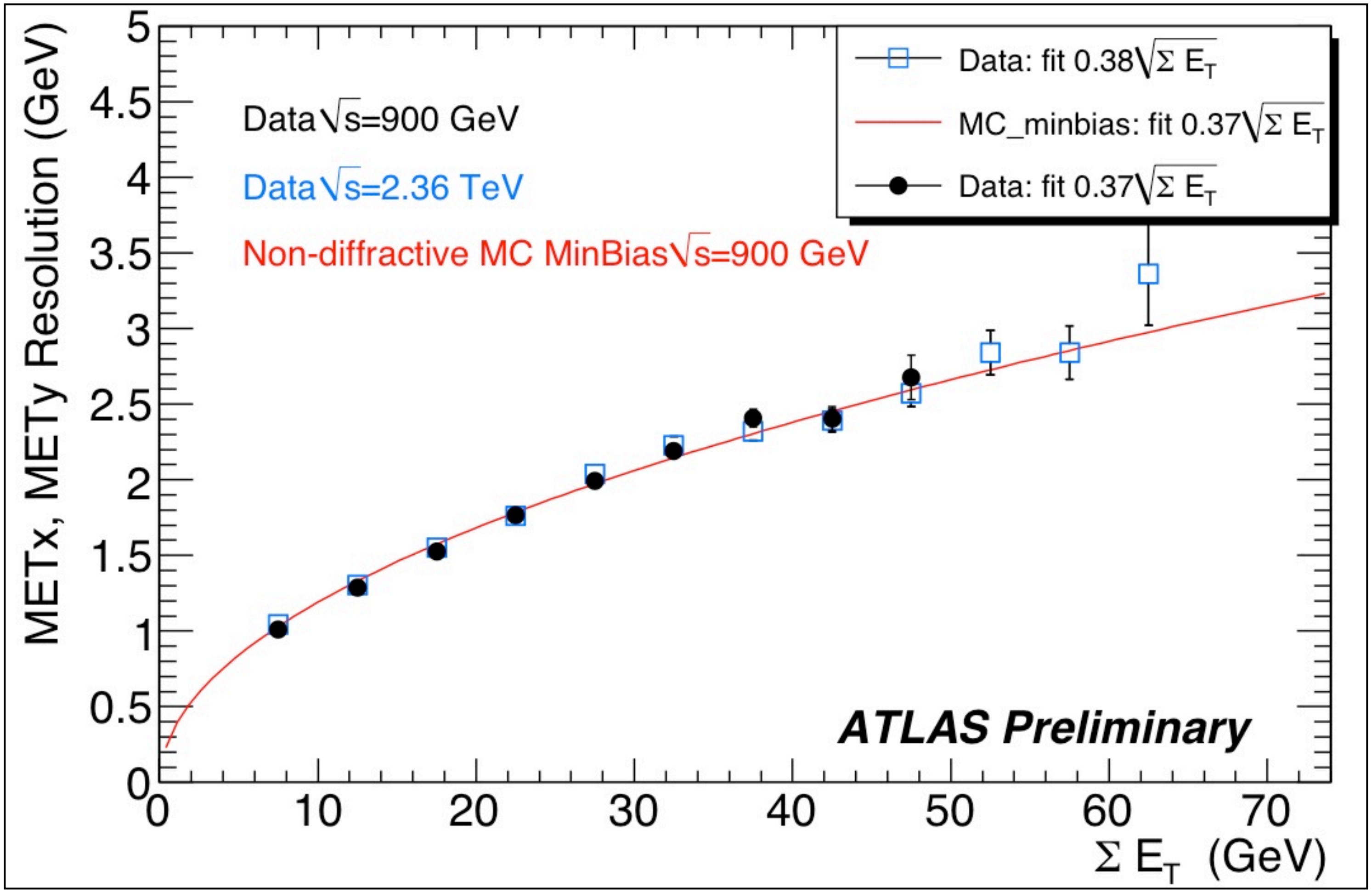
Missing Transverse Energy

- Sensitive to many detector problems
  - Noise, dead channels, miscalibration,…
- MEtx and MEty show the x- and y- component of the missing transverse energy vector



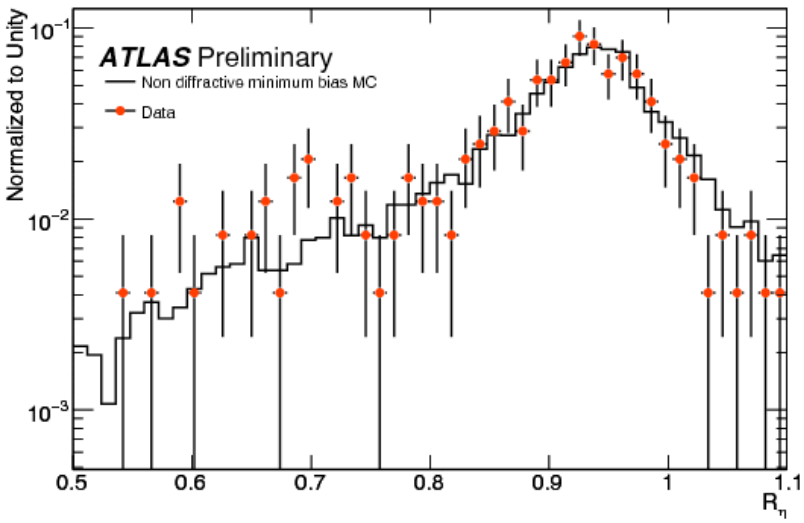


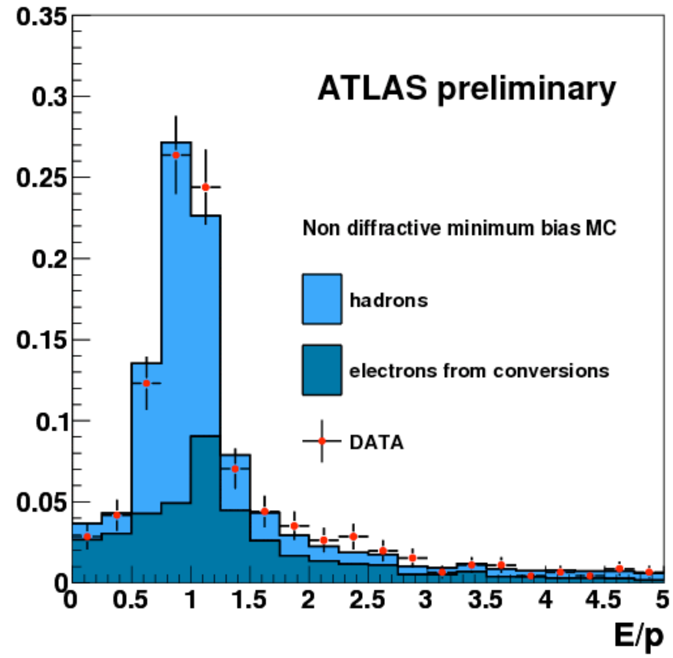
Missing E_T Resolution



- Data in good agreement with simulation

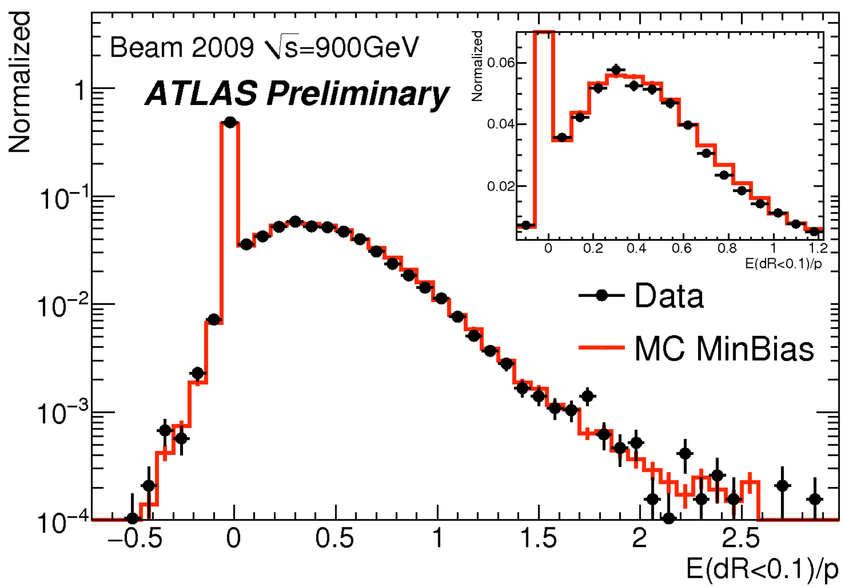
Electron and Photon Detection

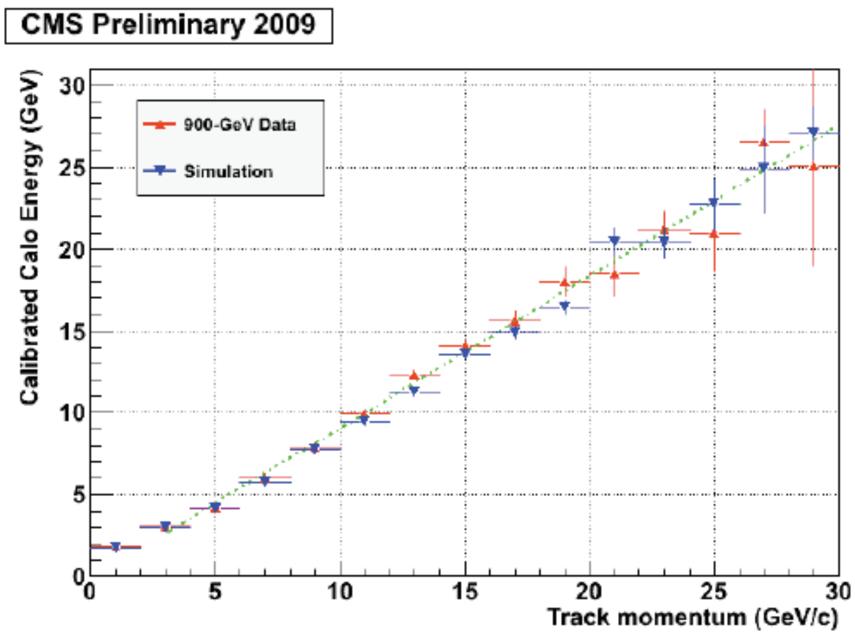




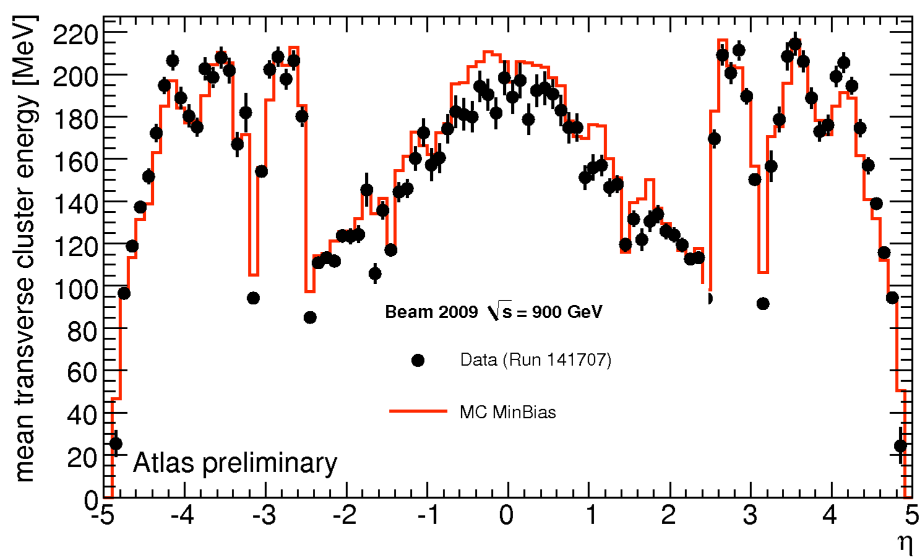
- Identification of photons and electrons relies on shower shape in electromagnetic calorimeter
  - Nice agreement of data and simulation
- Good agreement in E/p distribution
  - Compare energy measured in calorimeter to momentum in tracker
  - Probes material and electromagnetic energy scale

Calorimeter Response





- Response to single hadrons well understood
- Also good agreement vs eta
  - Covering many detector technologies



Conclusions

- **We know** the Standard Model describes all collider data so far
  - Great advances were made by the Tevatron
    - in probing strong and electroweak interactions
    - Searching for many new physics scenarios
- **We hope to discover** new particles that address the deficiencies of the Standard Model, e.g.
  - Dark Matter (Supersymmetry)
  - Hierarchy Problem (Supersymmetry, extra dimensions,…)
  - Something unexpected
- The Tevatron will continue to test the SM and the LHC will soon rival it in discovery potential
  - The 2009 pilot LHC run shows that the detectors work very well
  - The 2010/2011 run should deliver enough luminosity to start probing the Higgs boson and new physics

Exciting times are ahead of us!